Update to the NEMS Wind Model

Chris Namovicz

Renewable Energy Modeling Summit

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cnamovicz@eia.doe.gov

202-586-7120

Major Model Changes for Wind

- Cost/impacts of intermittency
  - Fixed limit on intermittent's share of regional generation in AEO2002
  - Flexible, cost-based approach in AEO2003
- Learning for cost and performance (see AWEA paper or NEMS documentation)
  - Large capital cost reductions, fixed performance in AEO2002
  - Small capital cost reductions, performance based on experience in AEO2003

Intermittency: Background

- Increased importance of wind in “high renewables” scenarios not reflected with fixed penetration limit
- Penetration limit may not reflect gradual increase in “real-world” costs with penetration
  - Costs are assumed “all or nothing”
  - Simple representation of several complex interactions

AEO2002 Model Structures

- Penetration limit
  - 10 to 15% of Regional Generation
  - Applies to Solar and Wind, but only Wind is really affected
- Capacity Credit
  - 75% of Regional Peak-load Capacity Factor
  - Also applies to all intermittent technologies

Developing a Theoretical Basis

- No present-day analogs for large, NERC-like regional systems
  - Denmark has high wind penetration, but is not a "stand-alone" reliability region
  - Wind is approx. 15% of Danish generation, but only 1-2% of NORDEL (the Scandinavian equivalent to a NERC region)
- Actual effects are thus not yet known

Theoretical Basis (con't)

- Recent work has focused on cost of ancillary services for wind-induced system imbalances
  - Without "penalties", marginal imbalance/ regulation costs tend toward net zero
  - With unbiased generation forecasting, output is equally likely to be "short" or "long"
  - Costs ultimately reflect the addition of "firm" capacity to ensure market liquidity/adequate reserve

Theoretical Basis (con't)

- 3 ISO/RTO's have actual "capacity markets"
  - PJM just started to allow intermittent resources to compete in capacity market (effective this month)
    - Based on "peak period" capacity factor (approx. 20%)
  - NYISO and New England ISO allow intermittent resources using average annual capacity factor to de-rate capacity
- FERC prefers markets that do not impose "arbitrary" penalties on intermittents

Theoretical Basis (con't)

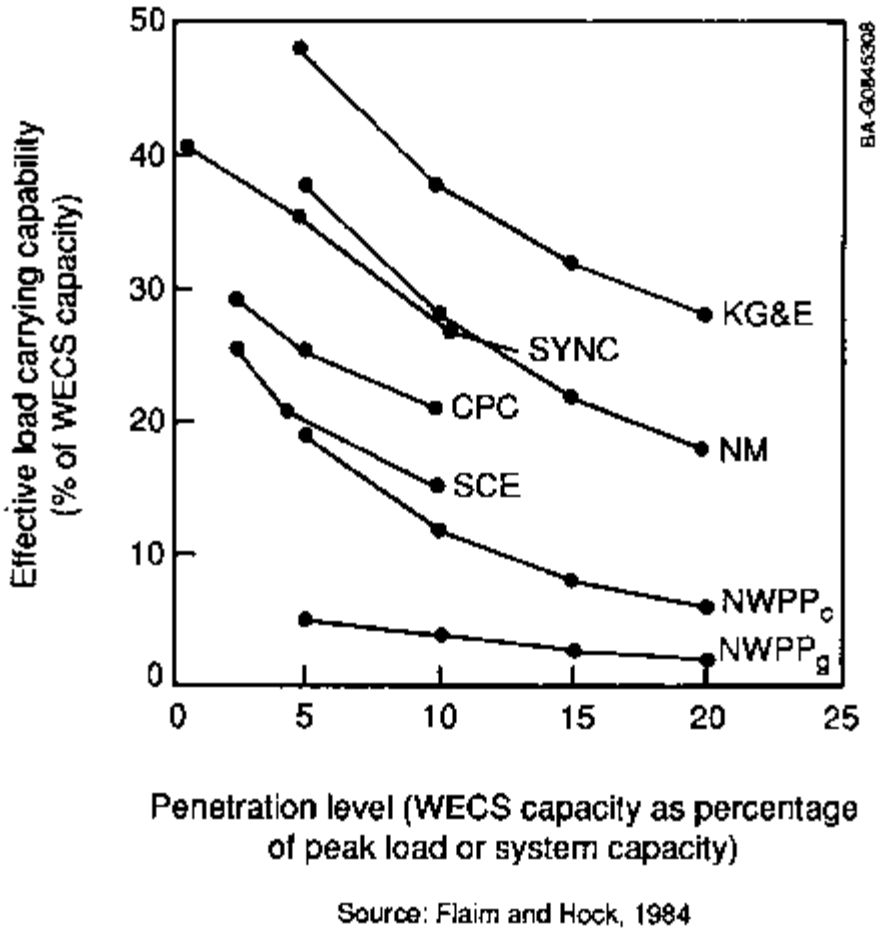


Figure 4-1. Wind generation ELCC as a function of penetration level

- Early studies (1980's) simulated reliability impacts of wind penetration
  - At low penetrations, wind can contribute to system reliability
  - At higher penetrations, capacity credits decline

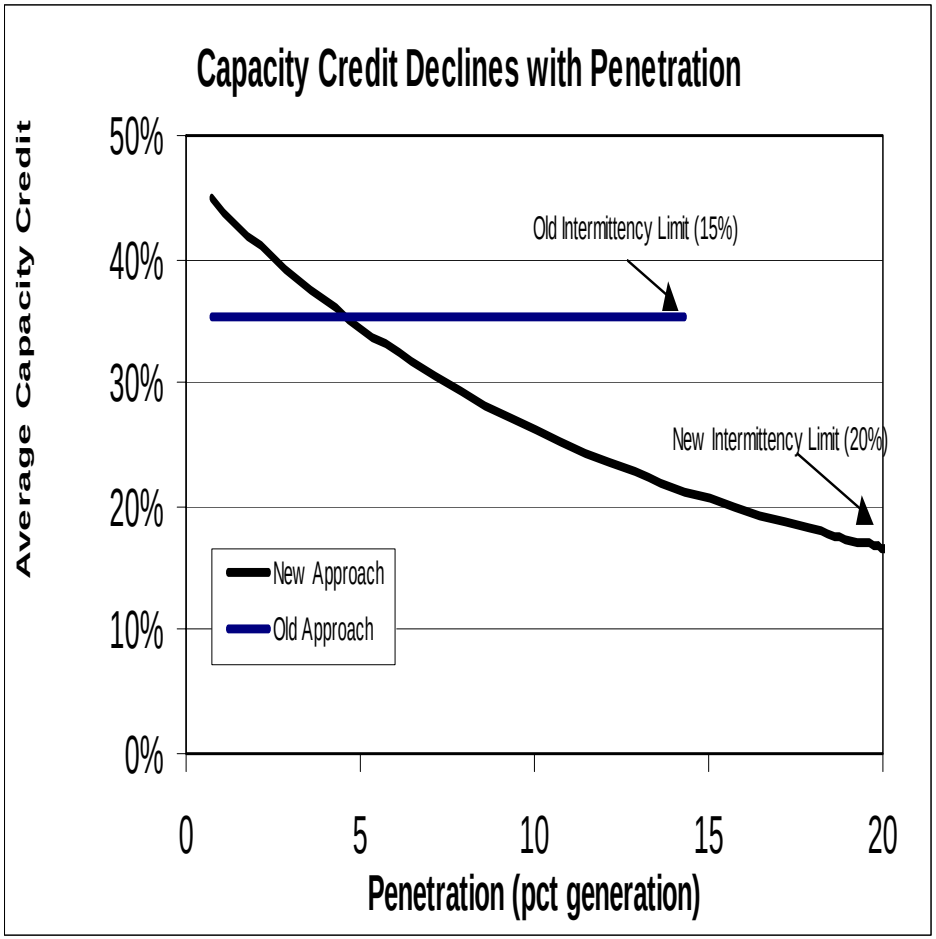
Model Needs

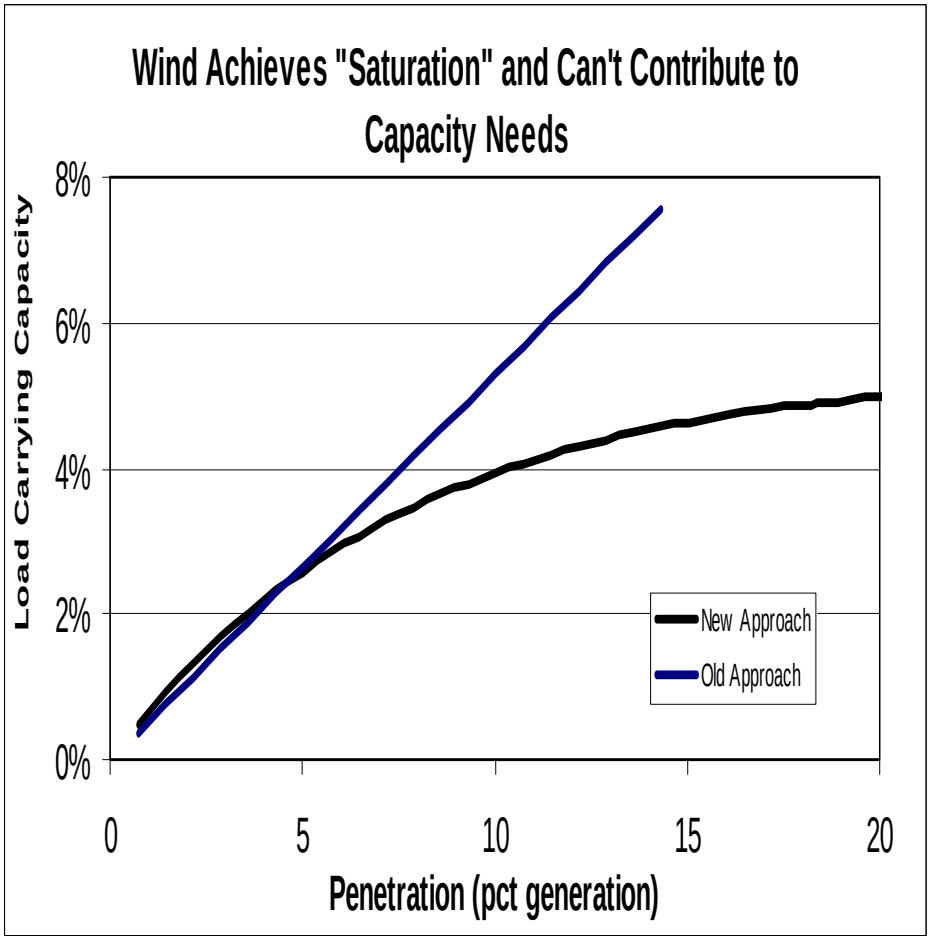
- No “show-stoppers” support limits on intermittent penetration
  - Many technical issues have already been addressed
  - Reliability issues will reveal themselves through increased market costs
- Goal: develop algorithm that reflects bulk of market costs

Selected Approach

- Fixed capacity credit is replaced with variable capacity credit which is a function of intermittent penetration
- Approach allows higher penetration of intermittent capacity, but requires increasing investment in "back-up" capacity
  - Higher penetration levels imply close to 1:1 back-up for each MW of wind
  - Intermittents effectively become "fuel-saver"

How it Looks


Capacity Credit Declines with Penetration
Average Capacity Credit
50%
40%
30%
20%
10%
0%
Old Intermittency Limit (15%)
New Intermittency Limit (20%)
New Approach
Old Approach
0
5
10
15
20
Penetration (pct generation)


Wind Achieves "Saturation" and Can't Contribute to Capacity Needs
Load Carrying Capacity
8%
6%
4%
2%
0%
New Approach
Old Approach
0
5
10
15
20
Penetration (pct generation)

Recent Work

- Developing additional analysis to improve parameters
  - Simple wind/grid reliability model to evaluate parameters for capacity credit
  - Analysis of low-load periods to develop methodology to account for wind curtailment
    - Currently accounted for through 20% limit on intermittent generation
    - Should be able to directly accounted for these costs

Closer Examination of Capacity Credit for Wind

- Develop a simplified grid reliability model to improve understanding of wind/grid interaction
  - Based on NEMS regional capacity
  - Evaluates “Reliable Load Carrying Capacity” based on “5 nines” criteria
  - Uses assumed statistical parameters for existing capacity and incremental wind capacity
  - Looks at effect of geographic diversity of wind resource

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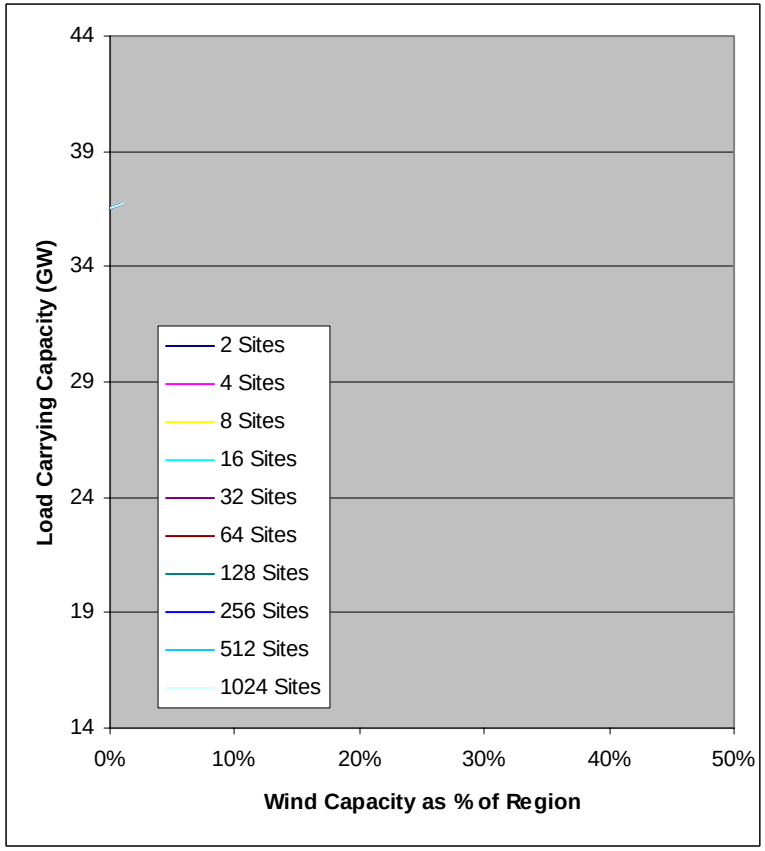
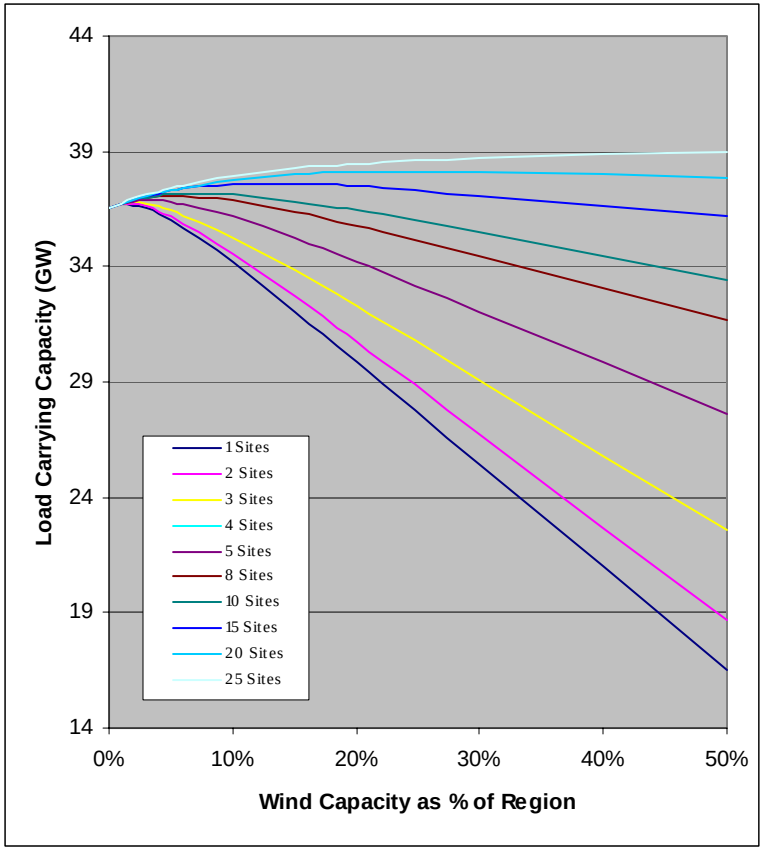
Load Carrying Capacity of Wind

- How does geographic diversity of wind resource affect reliable load carrying capacity?

Assume each site is 10% correlated with each other site: contribution to LCC is limited, even with many sites

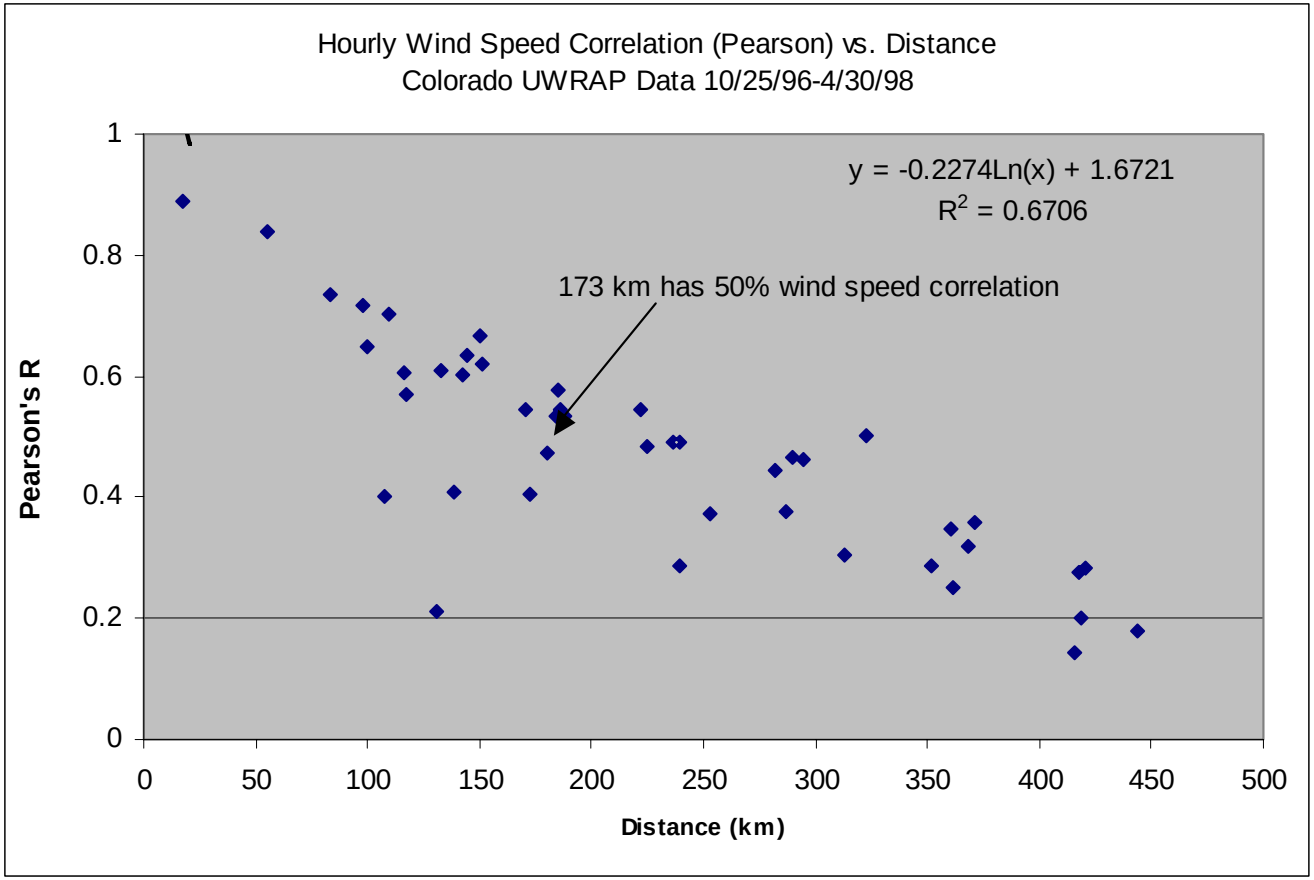


Assume each site is 50% "chain" correlated with adjacent sites: contribution to LCC improves with increasing number of sites



Wind Site Correlation

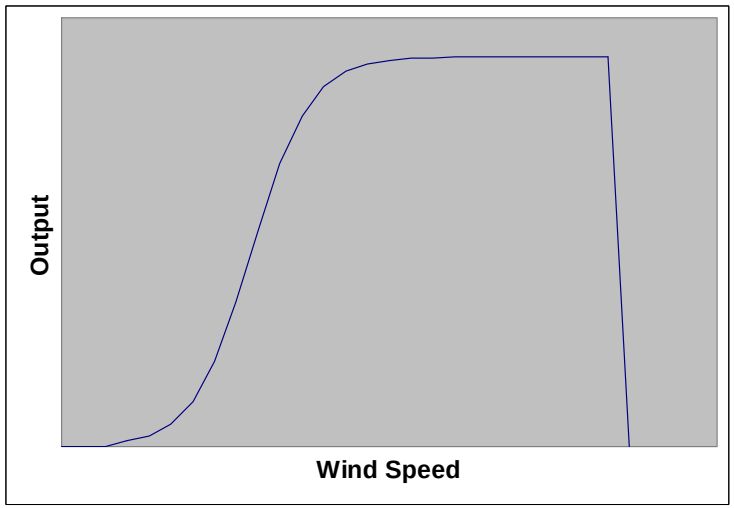
- Correlation between sites drops off quickly with distance, but weak correlation remains even at relatively long distances.
  - Correlations stronger if longer averaging time is used



Data and Analysis Needed

- Time-of-day correlations among windy sites in regions of interest
- “Monte Carlo” simulation of wind/grid interaction
  - Confirm validity of applying statistical techniques to non “normal” data
  - Potentially account for more subtle correlation among windy sites

Wind Turbine Output is Not "Normal"



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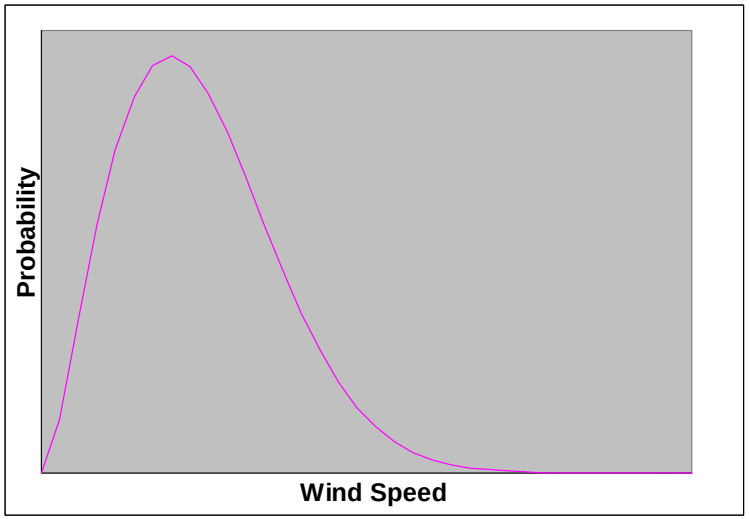

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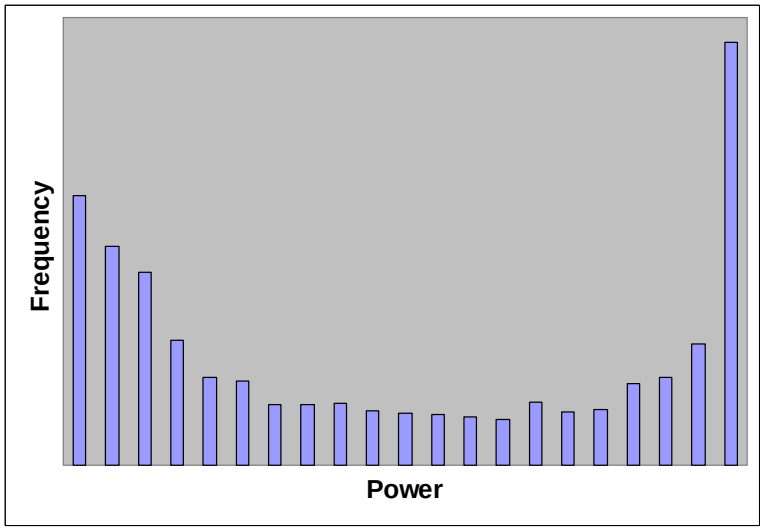

Analyzing Wind Curtailment

- At high penetration, “surplus” wind production during low-load periods may be curtailed to avoid undesirable cycling of coal and nuclear steam plants.
  - Cost is born by wind operation in form of lost revenue (energy that wasn’t generated that could have been)
- Modify NEMS to discount low-load period capacity factors as curtailment thresholds are reached
- Apply similar statistical approach described for “Capacity Credit” to determine parameters

Revised Approach: Details

$$\overline{C}_p = \frac{((C_o / D)e^{D(P-L)}) - (C_o / D)}{P}$$

Where:

C_p is the average capacity credit at a penetration level of P and C_0 is the initial capacity credit at zero penetration

e is the base of the natural logarithm

P is the fraction of total intermittent generation across all generation for the region in the previous calendar year

L is an "offset" factor (not currently used)

D, the exponential decay factor, is calculated from:

D=-ln(2)/H

Where H is the "half-life" parameter for the function